

BIOGRAPHY

Bedford A. Lampkin is a research scientist in the Manned Spacecraft Simulation Branch at Ames Research Center of the National Aeronautics and Space Administration. He joined Ames in 1955, and spent several years in stability and control work with the Ames Unitary Plan Wind Tunnel Group. Currently he is working with simulation studies of various aspects of space navigation. Mr. Lampkin graduated with a Bachelor of Science degree in electrical engineering from Alabama Polytechnic Institute (Auburn University) in 1950. Prior to his joining NACA, four years were spent as a naval aviator. He has been coauthor of several NACA and NASA publications.

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SEXTANT SIGHTING PERFORMANCE FOR SPACE NAVIGATION

USING SIMULATED AND REAL CELESTIAL TARGETS

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The feasibility of using a hand-held sextant for taking navigation measurements from on board a manned spacecraft is being studied at Ames Research Center. It would be advantageous to use a reliable, light-weight, hand-held instrument instead of a relatively complex, vehicle-mounted, automatic or semiautomatic device for taking such measurements if it provided sufficiently accurate angular measurements. The primary objective of the Ames research program is to determine the operational feasibility, scope of application, and accuracy of the manual measurement technique. A flight simulation facility has been used for examining navigator performance and the operational problems of the sighting task with hand-held sextants. Measurements of real star and lunar landmark angles are being obtained to evaluate the problems associated with absolute sighting accuracy. The accuracy typically considered necessary for space navigation is 10 arc seconds. A sighting experiment on board the Gemini spacecraft will be conducted to examine in a more realistic environment the feasibility and operational problems of using a hand-held navigation sighting instrument and to validate the results of ground-based investigations. The purpose of this paper is to describe some results of this program.

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The Ames Midcourse Guidance and Navigation Simulator (Fig. 1) was used to investigate the navigator's performance with the sextant. This simulator is composed of a simulated command module of a space vehicle and a visual scene simulating a 25° portion of the sky. The cab and the visual scene are 40 feet apart. The cab is mounted on an air bearing and has a control system so it can simulate the three-axis oscillatory motion of an actual vehicle during midcourse planetary flight. Seating is provided for three occupants of the cab with the center seat being used as the navigator's sighting station. The visual scene has both collimated and uncollimated stars as well as a nominally collimated lunar landmark.

Several sighting tasks were examined. These were sighting performance during training, a comparison of sighting performance with a hand-held sextant and a gimbal-supported sextant, and the effect of vehicle motion on sighting performance.

The criterion of performance was the repeatability of a group of ten measurements about the average measured value. This method is analogous to scoring a rifle marksman on how close together he spaces a group of ten shots without regard to how close the shot pattern is to the bullseye. If the distance of the shot pattern from the bullseye is defined, then presumably the cause of this miss distance can be analyzed and corrected. In the present case the bullseye corresponds to the absolute angle being measured by the sextant. Since this angle is difficult to define to our required accuracy, the use of the repeatability or standard deviation of measurement as a performance criterion allows us to examine more experimental variables in a given length of time.

The first series of sighting experiments were conducted with a Navy Mark II Mod 0 hand-held sextant. This instrument shown in Fig. 2 is a two line of sight marine sextant of World War II vintage having a telescope magnifying power of 3. The minimum readout on the vernier scale is 0.1 minute of arc.

The measurement technique was that typically employed with a two line of sight sextant. In measuring the angle between a simulated star and lunar landmark, the navigator obtained the lunar landmark in both the primary and secondary lines of sight. By rotating the indexing arm and the index mirror, he adjusted the secondary line of sight so that he could observe the proper star. With the two targets in the telescope field of view, he made fine adjustments to the index mirror placing the star so that with a slight rolling motion of the sextant about the primary line of sight, the star moved on an arc which passed through the center of the crater. At this time he could read the angle directly from the indexed arc and vernier scale.

The first problem that we encountered was the need for training our experimental subjects. The subjects consisted of three Air Force navigators attached temporarily to Ames Research Center to participate in these experiments and professional employees working in related fields of interest. The Air Force navigators had extensive experience in the use of a bubble sextant; however, they required further training to use the two line of sight sextant effectively. The experimental sessions lasted for two weeks or ten working days. Figure 3 shows the variation of the average of all subjects' standard deviation during their initial two week experimental period. The initial value of 45 seconds of arc

standard deviation improved to 20 seconds of arc by the tenth day. Their sighting performance could probably have been improved with a longer training period. Of the ten working days, the first six were spent in training and the last four in obtaining data. Actually, one week of training would have sufficed for our purposes; however, it can be seen that after a weekend with no sighting exercises, performance degraded sufficiently to require an extra day of training. The maximum and minimum values of standard deviation for each test day are indicated by the dashed lines. These values tend to converge to the average values as the tests progressed.

As might be expected, motivation is extremely important in training for this sighting task. To encourage motivation, each subject was kept informed of his and the other subjects' performance progress; thus competition was developed among the subjects.

The Navy Mark II Mod O hand-held sextant was adapted to a set of cab-supported gimbals as shown in Fig. 4. These gimbals supported the weight of the instrument and allowed rotational freedom about three axes.

Using the hand-held and gimbal-supported sextants, the subjects obtained sighting data while the cab was stationary and while it was moving about the yaw axis. The results are shown in Fig. 5. In this figure the standard deviations are the averaged values for seven subjects. The cab motions were a sinusoidal yawing oscillation with an amplitude of $\pm 2^\circ$ and maximum rates of $1/2^\circ$, 1° , and $1-1/2^\circ$ per second. Two interesting features of Fig. 5 are that there is no significant advantage with either instrument in sighting performance and there is no degradation in sighting performance with an increase in yawing rate. The subjects

participating in this experiment preferred to use the gimbal-supported sextant and expressed surprise that their performance was not compatible with their preference. The subjects also stated their preference for a moving rather than a stationary cab as this made the sighting task more interesting. Cab motion apparently did not increase subject fatigue.

In the third simulation experiment, a second type of sextant was used - a Plath-Micrometer sextant (Fig. 6) which is a commercially available hand-held marine sextant. The telescope on this sextant had a magnifying power of 6 and a 30 mm objective lense. The minimum readout of the vernier scale was 0.2 arc minute; however, interpolations to 0.1 arc minute could be made accurately. Using this sextant improved sighting performance significantly as compared to performance with the previously discussed sextant.

With the Plath-Micrometer sextant, sighting data were obtained while the cab was in various combinations of motion about its three axes. The results (Fig. 7) give the average of several subjects' standard deviation for the stationary cab and with the cab in sinusoidal motion about various axes. Cab motions were limited to $\pm 2^\circ$ amplitude and $\pm 1\text{-}1/2^\circ$ per second maximum rate. These motions represent a fairly realistic spacecraft controlled limit cycle amplitude; however, the rate of $1\text{-}1/2^\circ$ per second is greater than would be expected.

Cab rolling motions appeared to affect sighting performance adversely. Without the rolling motion, standard deviations were less than 10 seconds of arc and with any combination of cab motion that included rolling motion,

they were greater than 10 seconds of arc. Subjective experience during this experiment indicated that sighting performance with cab motion is particularly amenable to training.

A second phase of our investigation of the manual measurement techniques concerned the problems associated with absolute accuracy. For this study we used real stars and lunar landmarks as targets. It was felt that this was the best way to study the absolute measurement problem and in addition this technique would tend to develop realistic sighting methods. In this study, angles between the lines of sight to real stars and lunar landmarks, either a lunar limb or crater, were measured and compared with the angles computed from Ephemerides to obtain the absolute accuracy of the measurement and the standard deviation of a series of measurements.

The instrument used in these experiments is shown in Fig. 8 and is a manually-operated and gimbal-supported sextant. The basic objective of this instrument design was to minimize the cost of fabrication by utilizing "off-the-shelf" components when possible, yet provide a sextant with the accuracy of measurement required in a space navigation sextant. The gimbal support allows rotational freedom about three axes. The sextant telescope has a magnifying power of 10 and a 5° field of view. The readout device includes a microscope for reading the indexing vernier and both sides of an indexed 6-inch circle. A trained operator is able to repeat the vernier alinement to 1 second of arc.

An index correction or zero bias correction was applied to the measurement data. This correction compensates for a misalignment of the two lines of sight with the zero index and for the individual bias of the

instrument operator. This correction varied among three individuals by as much as 20 seconds of arc and was obtained each night that data were taken. This correction was the average of several measurements obtained by having the same star in both lines of sight and placing the two images side by side. Rather than trying to superimpose a star on a star statically, it was found that better accuracy was obtained when the indexing mirror was offset slightly to allow the two images to be placed in lateral proximity.

The results obtained thus far are shown in schematic form in Fig. 9. For the sighting data indicated here, time of target superposition was recorded accurate to ± 0.2 seconds. The three diagrams represent the results of measuring target pairs of star-star, star-lunar limb, and star-lunar crater, respectively. In each of the three diagrams, the vertical axis represents the computed angle and the horizontal axis represents the measured angle. If the measured values agreed perfectly with the computed values, all data would fall on the solid line. It was found, however, that a bias and pattern of repeatability existed characteristic of three types of target pairs. The average bias in the measurement for the three target pairs of star-star, star-lunar limb, and star-lunar crater, respectively, is 6.2, 9.7, and 17.7 seconds of arc. The shaded sections in Fig. 9 indicate the limits about the average bias within which 60 to 70 percent of the individual measurements would fall. These limits for target pairs of star-star, star-lunar limb, and star-lunar crater, respectively, are ± 4.6 , ± 12.5 , and ± 20.2 seconds of arc. Further data are being obtained with which both the measurement technique and computational process may be improved to resolve or minimize the measurement bias.

The star-star target pairs being the best optical targets indicate the potential accuracy of the operator-instrument combination. The absolute angle between two stars is the least complex to compute. The computer program for ascertaining the absolute angle accounts for atmospheric refraction and annual aberration. The star-lunar limb and star-lunar crater computed angles are more liable to computational error because of the parallax effect on the measured angle and because of the complicated motions of the moon. An added complication to the measurement of star-lunar limb angles is the effect of irradiance. This effect on the sextant operator is to enlarge the apparent lunar disk size due to the brightness contrast of the lunar surface against the dark background. The correction for irradiance was obtained empirically and amounted to approximately 16 seconds of arc. Some of the problems affecting the measurement of star and lunar crater angle measurements are the difficulty of crater identification, the optimum crater diameter for star superposition, and an apparent shift in crater location due to the variation in shadow relief on the lunar surface.

A third step in the development of a manual measurement technique will be the Gemini T-2 experiment performed in the authentic spacecraft environment. The basic objective (Fig. 10) will be to evaluate the ability of a navigator using a hand-held sextant to measure the angles between various celestial bodies from on board the Gemini spacecraft. Other objectives of this experiment will be to correlate our simulation data with in-flight results, to determine operational problems, to assess the feasibility of the measurement technique, to assess target utility, and to benefit the development of space navigation technology.

An important step in the implementation of this experiment will be to procure a sextant that will meet the experimental requirements summarized in Fig. 11. Two sextants are presently being designed and are specified to be operationally accurate to within ± 10 arc seconds. The maximum weight of the instruments will be 6 pounds. The instruments must be operated and stored in the restricted space of the vehicle. It's maximum length along the primary line of sight is 8 inches. The eyepiece must provide both normal and long eye relief so it can be used with the navigator's pressure helmet visor up or down. Finally, the instrument is required to meet space flight qualification tests.

Of the various problems encountered, one of the most difficult to resolve will be the measurement errors induced by the spacecraft window. The window of the Gemini spacecraft, through which the astronaut will be sighting while operating the instrument, is roughly an elliptical shape and is composed of three panes of glass (Fig. 12). The factors chiefly responsible for distorting the target lines of sight will be the lack of flatness of the glass surfaces, the wedge angle between the two surfaces of each pane of glass, and the distortion of the glass panes due to a difference in pressure on either side of the glass. A fourth factor not directly attributable to the glass is the difference in the index of refraction of the light transmitting medium between the interior and exterior of the spacecraft.

Distortion of the glass panes due to lack of flatness, wedge angle, and pressure differential are being determined both analytically and by physical calibrations. Knowing the characteristics of the glass and

incidence angle and location of the incident rays on the window, we expect to resolve these errors to within 1 second of arc.

The correction for the difference in the index of refraction is more straightforward. Knowing the magnitude of measured angle, the spacecraft interior pressure and temperature, and the orientation of the lines of sight relative to the surface of the glass, we may resolve this correction.

The performance criteria of the Gemini T-2 experiment are predicated upon three factors. These factors are repeatability of sextant measured values, absolute accuracy of measurement, and the time required to perform the measurement task. The repeatability of the measurement values will indicate statistically the level of navigator performance. The measure of absolute accuracy will give the most definitive results of the experiment. The time required to perform the measurement task will indicate the time economy of the task, the fuel required for spacecraft control during the measurement task, and the flexibility of the measurement technique.

The results of the Gemini experiment will be valuable in the development of a reliable and accurate measurement technique for future spacecraft navigation.

FIGURE CAPTIONS

Fig. 1.- Photograph of Ames Midcourse Guidance and Navigation Simulator.

Fig. 2.- Photograph of Navy hand-held Mark II Mod 0 sextant.

Fig. 3.- The mean daily standard deviation for all subjects using a
Navy MK II Mod 0 sextant.

Fig. 4.- Photograph of gimbal-supported Navy MK II Mod 0 sextant.

Fig. 5.- The comparison of sighting performance using a hand-held sextant
and a gimbal-supported sextant with an increase in yaw rate.

Fig. 6.- Photograph of the Plath-Micrometer sextant with a 6 power
telescope.

Fig. 7.- The effect of vehicle motion on sighting performance using a
hand-held Plath-Micrometer sextant.

Fig. 8.- A gimbal-supported sextant with a 10 power telescope and 1 second
of arc second readout capability.

Fig. 9.- Schematic diagram showing the sighting performance attained
with real star and lunar landmark targets.

Fig. 10.- Objectives of the Gemini T-2 experiment.

Fig. 11.- Sextant requirements for Gemini T-2 experiment.

Fig. 12.- Illustration of astronaut performing the sextant sighting task
seated in the Gemini spacecraft.



Fig. 1

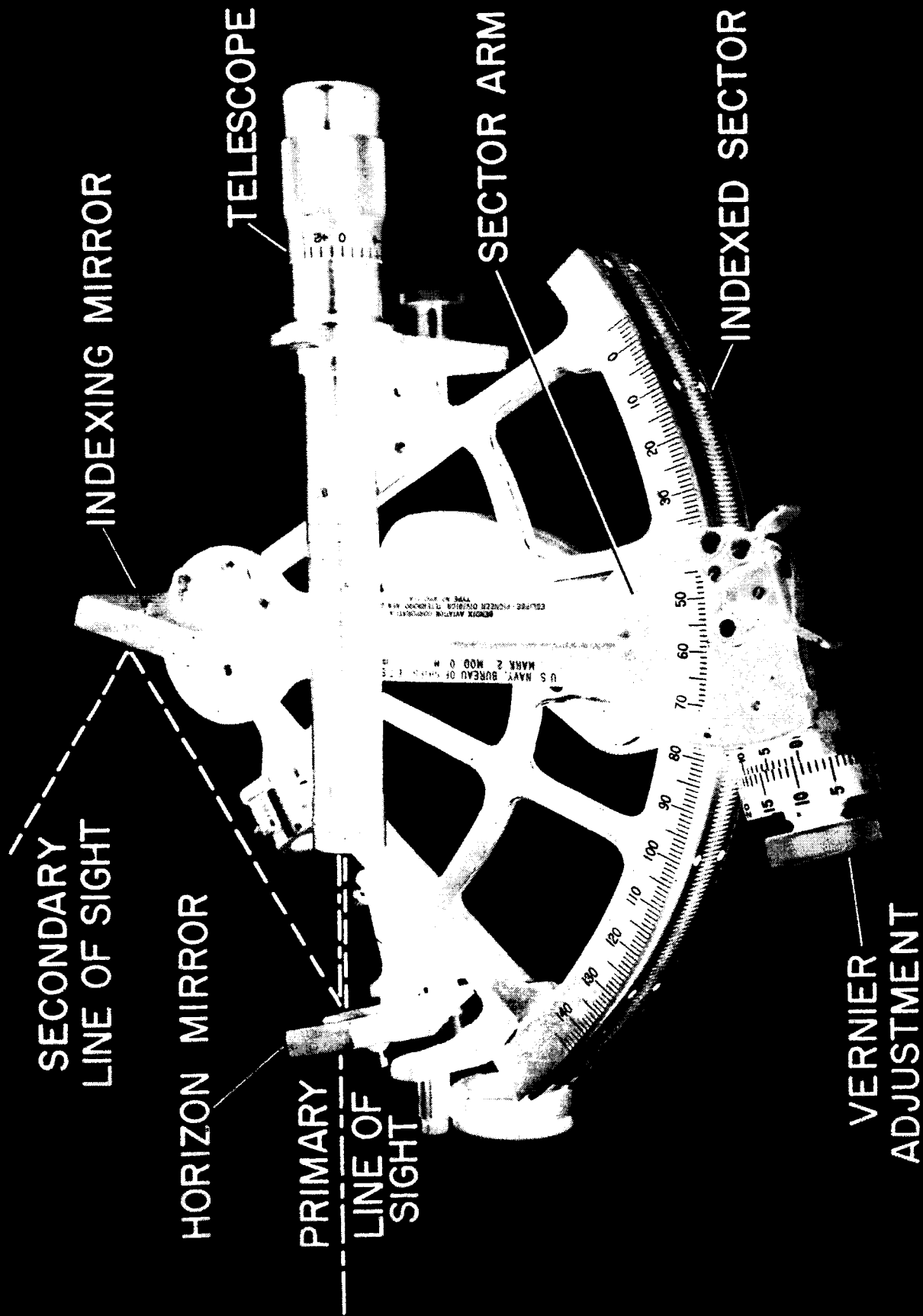


Fig. 2

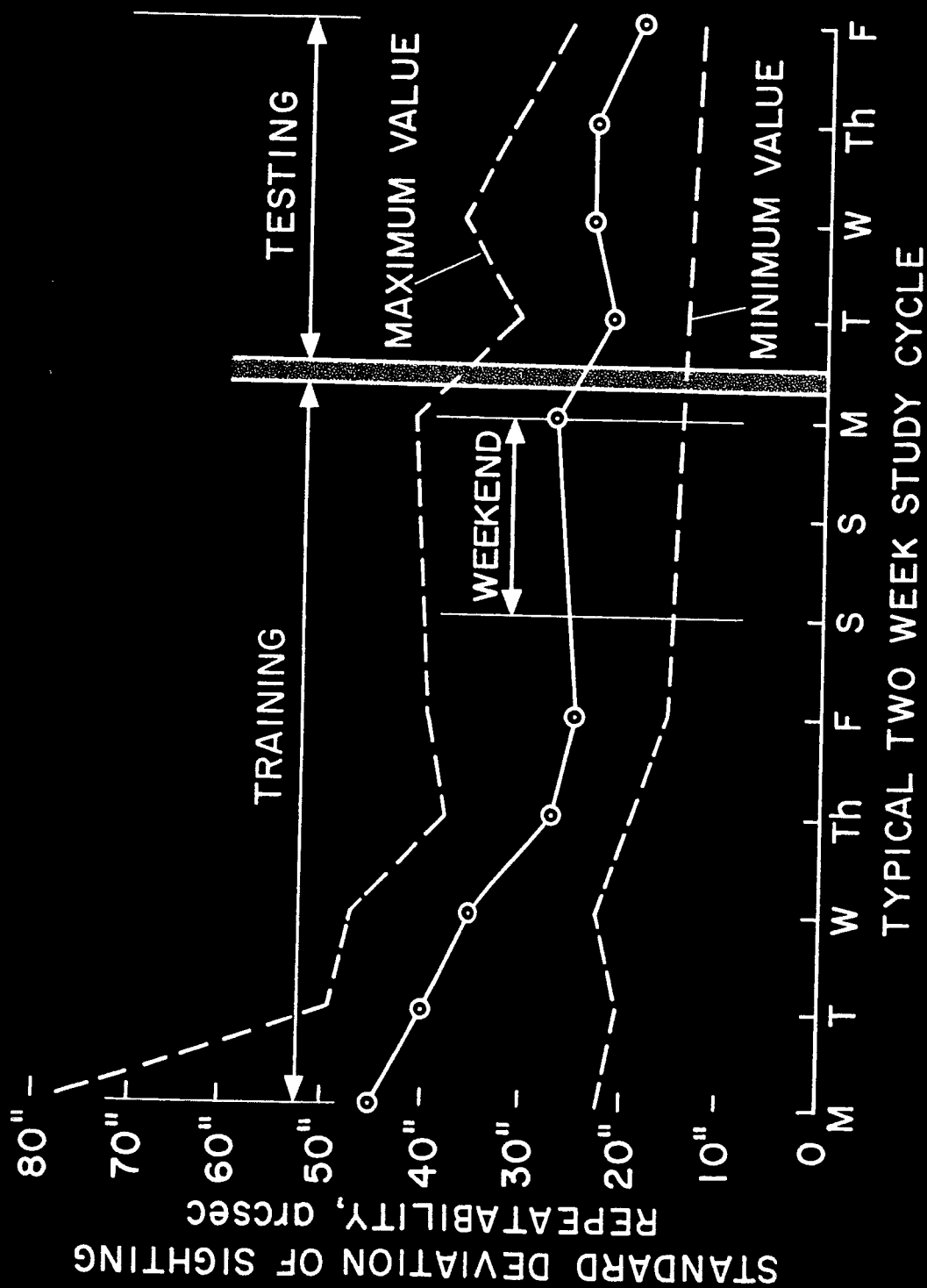


Fig. 3

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Fig. 4

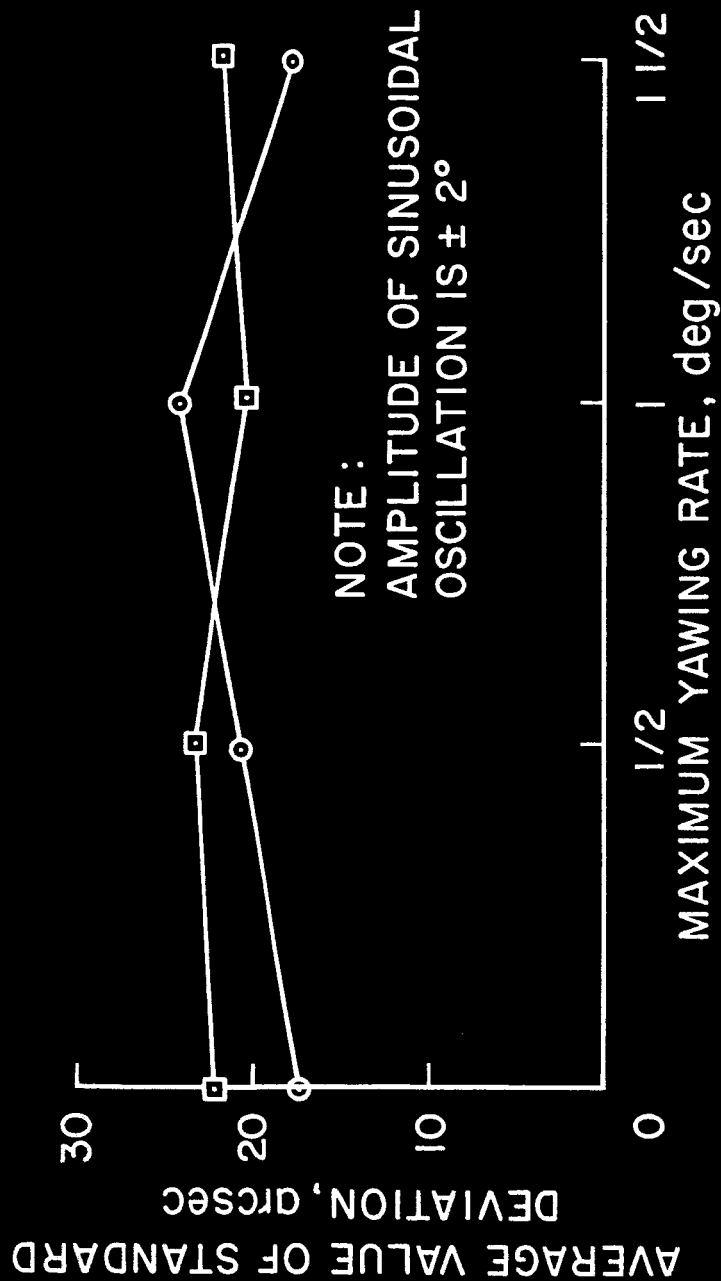


Fig. 5

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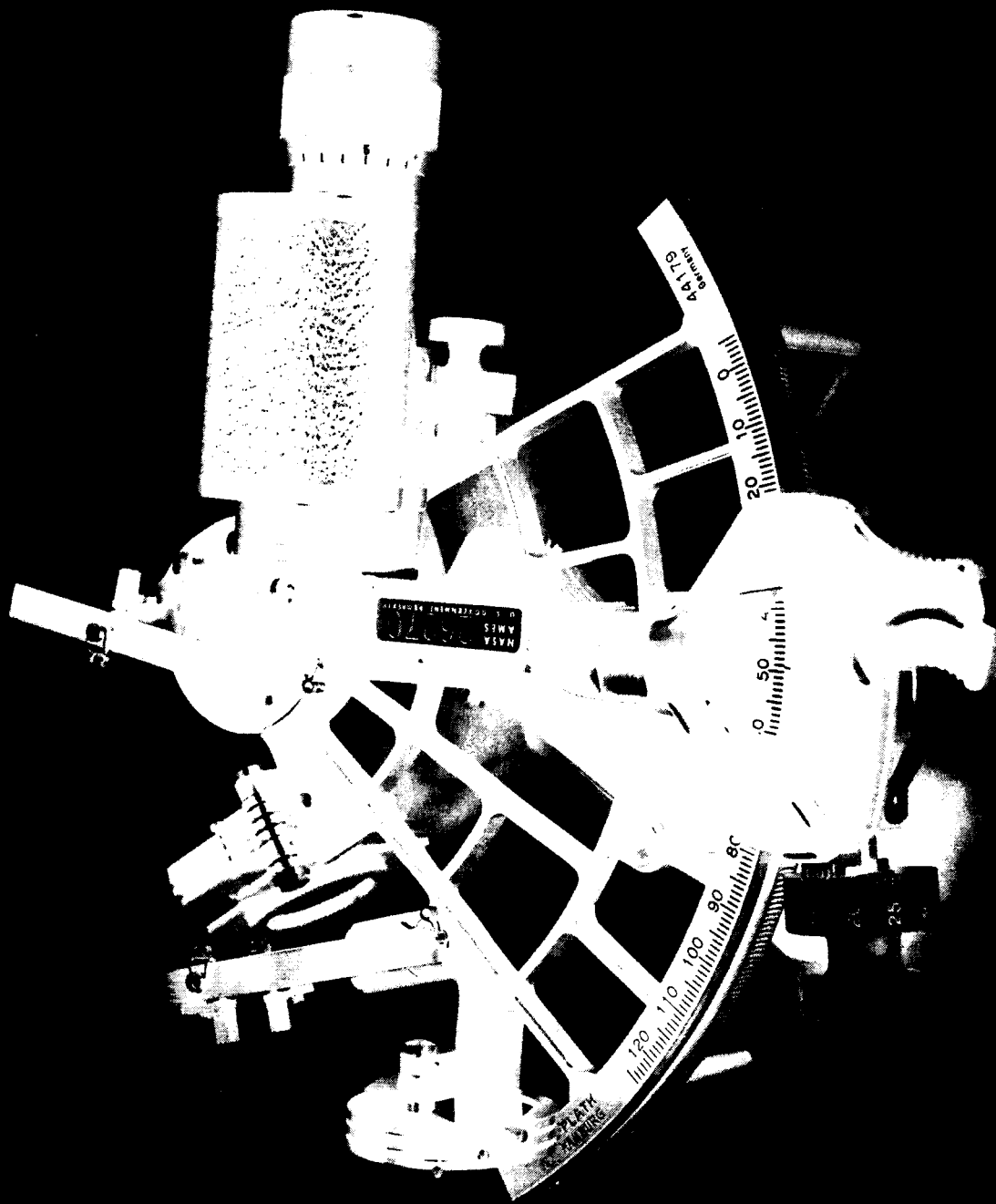


Fig. 6

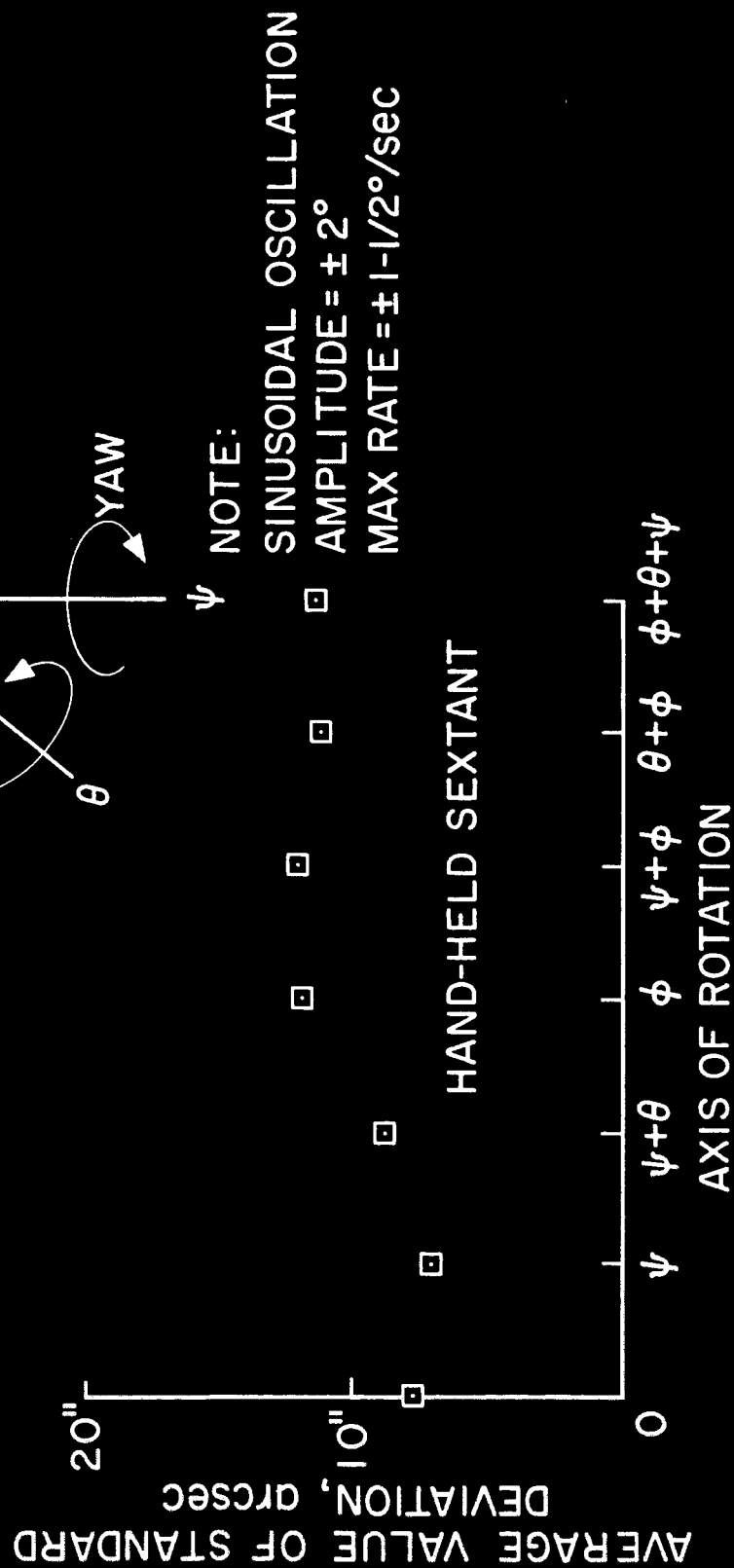


Fig. 7

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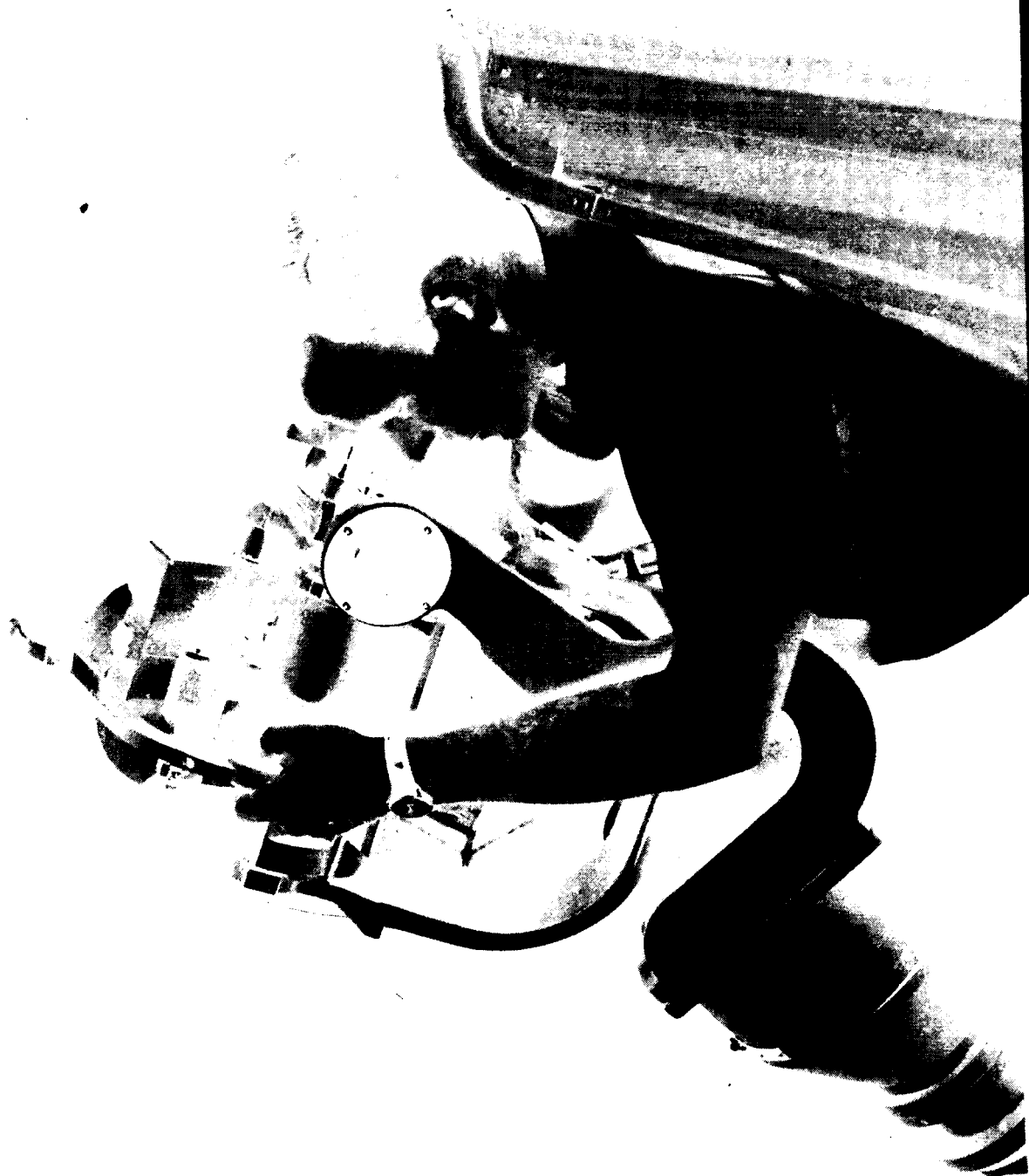


Fig. 8

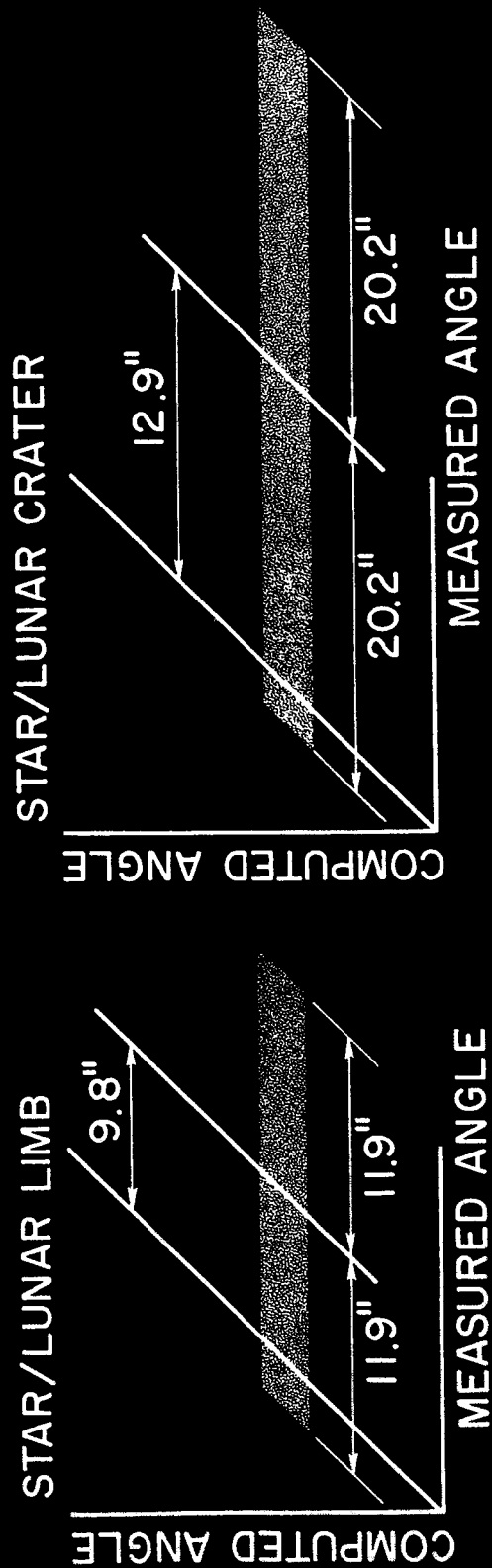
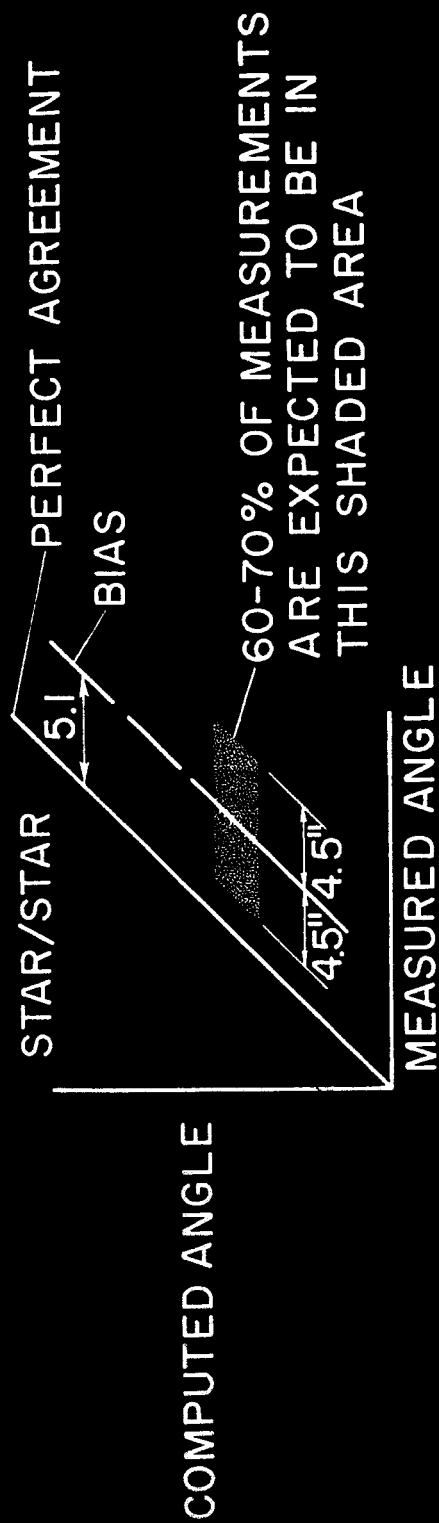


Fig. 9

1. MAKE NAVIGATIONAL MEASUREMENTS FROM THE GEMINI SPACECRAFT WITH A HAND-HELD SEXTANT CAPABLE OF ± 10 arcsec ACCURACY
2. EVALUATE THE NAVIGATOR'S ABILITY TO PERFORM THE MEASUREMENT TASK IN AN AUTHENTIC SPACE ENVIRONMENT
3. CORRELATE SIMULATION DATA WITH IN-FLIGHT RESULTS
4. DETERMINE OPERATIONAL PROBLEMS AND ASSESS THE FEASIBILITY OF THE MEASUREMENT TECHNIQUE
5. ASSESS TARGET UTILITY
6. BENEFIT THE DEVELOPMENT OF SPACE NAVIGATION TECHNOLOGY

Fig. 10

1. OPERATIONAL ACCURACY — ± 10 arcsec
2. WEIGHT — 6 lb MAX
3. SIZE — TO MEET THE AVAILABLE GEMINI OPERATING
AND STOWAGE SPACE, MAXIMUM LENGTH
ALONG PRIMARY LINE OF SIGHT OF 8 in
4. OPTICS — NORMAL AND LONG EYE RELIEF OPTICS
REQUIRED FOR ALTERNATE PRESSURE
HELMET VISOR POSITION
5. SPACE FLIGHT QUALIFIED

Fig. 11

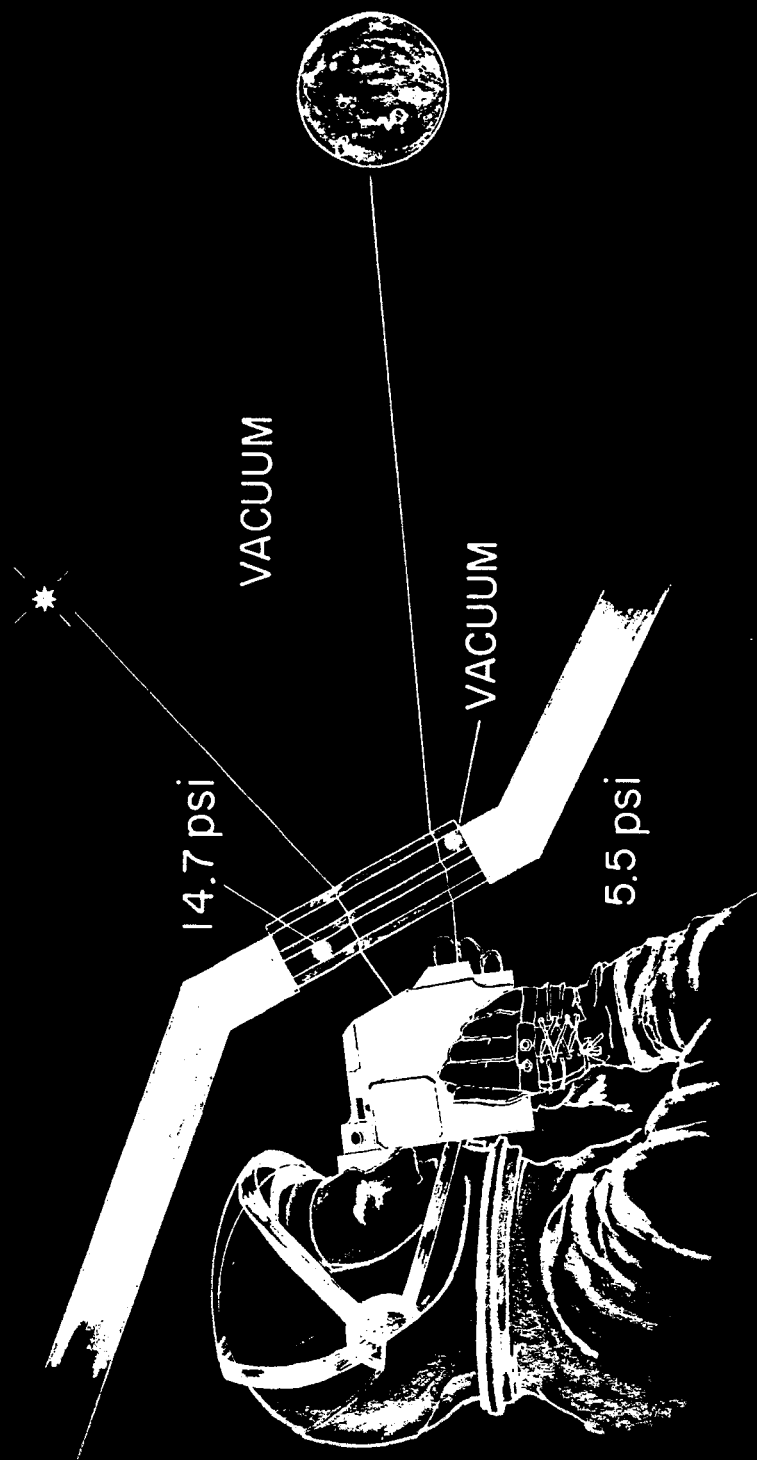


Fig. 12